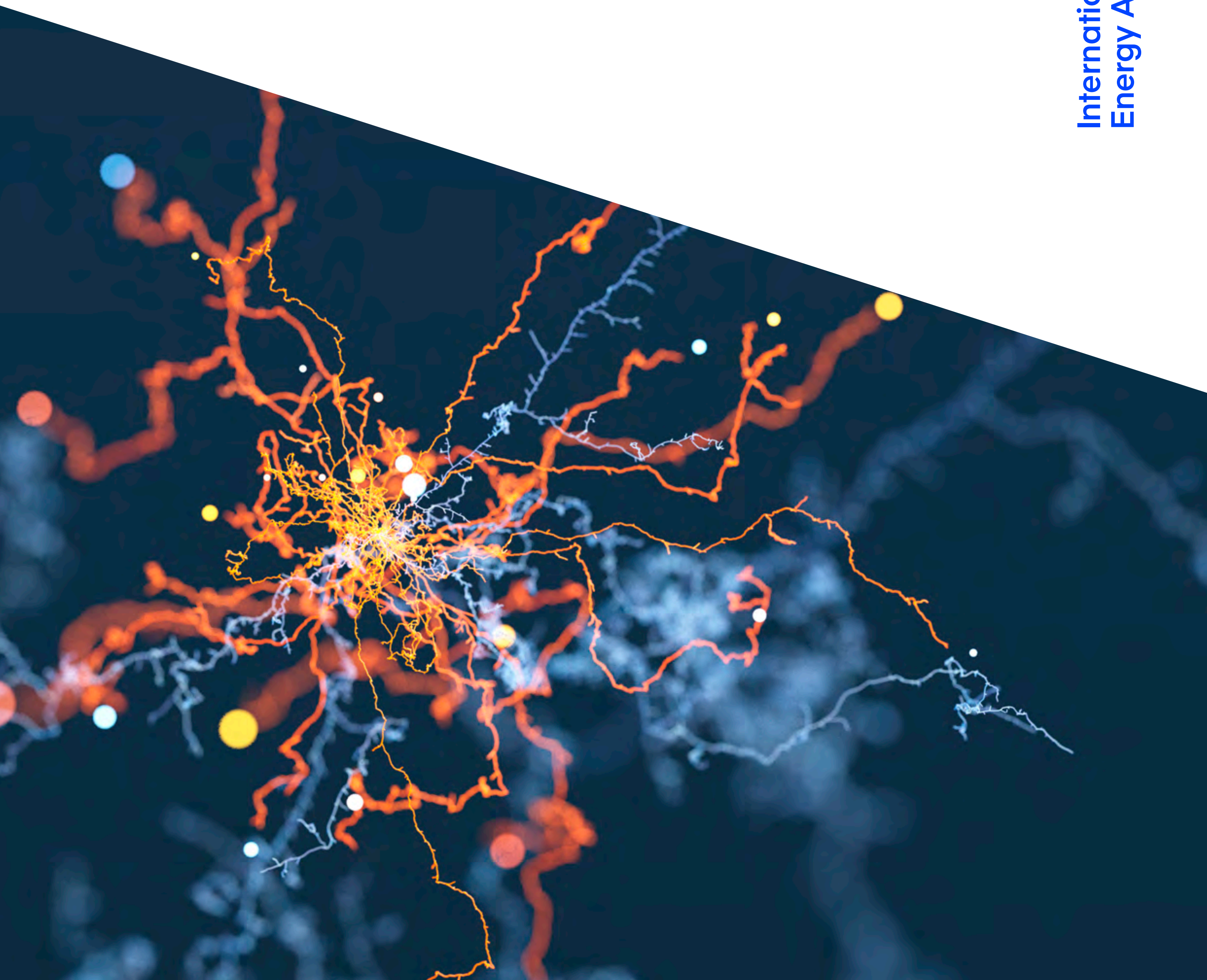
G20 INDONESIA 2022

Security of Clean Energy Transitions

International Energy Agency



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Abstract

This report examines the evolving challenges of maintaining energy security in the context of clean energy transitions on the pathway to net zero emissions. The report reflects on the security implications of the triple global crisis, the climate emergency, the global energy crisis and the social and economic implications of the Covid-19 pandemic.

The report highlights key energy security concerns during energy transitions and provides governments, notably within the Group of Twenty (G20), with policy recommendations for maintaining and improving energy security, while accelerating clean energy transitions to address the triple crises.

In the context of Indonesia's G20 Presidency, the Ministry of Energy and Mineral Resources invited the International Energy Agency (IEA) to produce a second edition of its Security of Clean Energy Transitions report, the first having been published in 2021, building on the G20 Naples Principles.

In the run up to the Bali G20 Energy Transitions Ministerial in September 2022, this report is intended to support discussions among the G20 countries and further elaborate on the G20 Naples Principles, agreed at the G20 energy ministers' meeting in Naples in 2021, by providing analysis, insights and recommendations.

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Aad van Bohemen, Advisor to the EMS Directorate and Jason Elliott, Acting Head of the IEA Energy Policy and Security Division, provided expert guidance and advice. The report was co-ordinated by Sylvia Beyer and Kiyomi Hyoe. The main contributors (in alphabetical order) were: Toril Bosoni, Jose Miguel Bermusez Menendez, Jean-Baptiste Dubreuil, Carlos Fernandez Alvarez, Keith Everhart, Paolo Frankl, Ronan Graham, Ilkka Hannula, Milosz Karpinski, Tae-Yoon Kim, Kevin Lane, Gergely Molnar, Kristine Petrosyan, Divya Reddy, Uwe Remme, Cornelia Schenk, Jennifer Thomson and Jacques Waritchet.

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Introduction

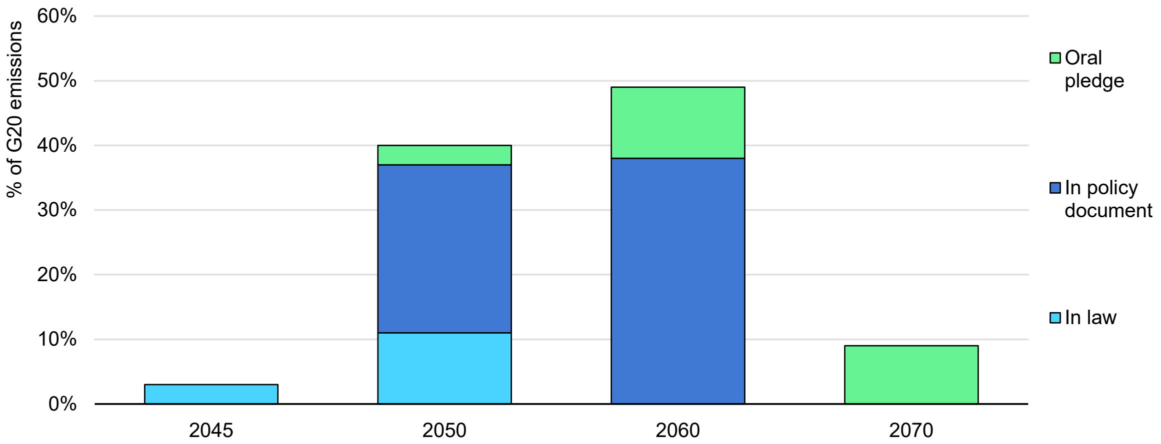
Unprecedented events – the global coronavirus pandemic (Covid-19), the climate emergency and the turbulence in global energy markets, resulting from the Russian Federation's (hereafter, "Russia") invasion of Ukraine – have shocked the world in 2022. Unprecedented challenges, stemming from the triple global crisis require extraordinary actions to foster solidarity and fight the first and largest global energy crisis.

In 2022, the G20's lead on energy security and solidarity is more important than ever. Even before these events, the G20 has discussed and tackled a variety of related issues, proposing solutions and calls for action. In 2021 energy ministers at the G20 Ministerial in Naples, Italy, agreed on the G20 Naples Principles, which give guidance on collaboration towards maintaining and improving energy security during energy transitions.

The objective of this report is to update and deepen the analysis, based on the G20 Naples Principles and with a specific focus on ways of maintaining and improving energy security during the current global energy crisis. It provides a series of recommendations to allow G20 countries to achieve secure clean energy transitions through important near-term actions which are aligned with long-term goals.

Importantly, G20 countries have pledged net zero emissions by or around mid-century (see figure below). In the long term, accelerating clean energy transitions will support energy security as it will reduce the need for fossil fuel imports and consumption.

Share of G20 emissions covered by net zero emissions pledges, by status and target date



Source: IEA (2021), adapted from Number of countries with NDCs, long-term strategies and net zero pledges, and their shares of global CO_2 emissions in 2020 – Charts – Data & Statistics - IEA, What to expect from the new WEO-2021 – Analysis - IEA.

In the short term, there is a need to maintain energy security and rebalance supply and demand of energy by reducing demand and increasing supply, maximising the existing infrastructure, while radically reducing emissions of oil, gas and coal. This will help decrease pressure on global energy markets and prices.

In March and April 2022, IEA member countries agreed to take collective action to release oil from their strategic reserves; the largest collective actions in the history of the IEA. IEA members underscored their strong and unified commitment to stabilising global energy markets, which was welcome by many G20 members. As these collective actions show, international collaboration and concrete actions are critical in ensuring the stable supply of energy, notably for developing economies.

As underlined by the IEA report, Net Zero by 2050: A Roadmap for the Global Energy Sector, energy security becomes even more important on the way to net zero. Governments and industry must boost preparedness and resilience in the face of new and more frequent threats beyond traditional energy infrastructure disruption, such as cyberattacks and extreme weather events, particularly with regard to electricity infrastructure. The establishment of reliable and cost-effective supply chains for clean hydrogen and ensuring the adquacy of the global supply of critical minerals to meet the demand from ramping up clean energy technologies is part and parcel of achieving secure clean energy transitions.

This report analyses the importance of energy efficiency in emerging economies in light of the cost of living crisis. It then discusses the importance of enhancing access to affordable and reliable electricity, touching on elements including faster deployment of a broad portfolio of renewable energy and ways to secure the integration of higher shares of variable renewables while boosting electricity security. Chapter 3 deals with how to strengthen preparedness, focusing on oil and gas security, the importance of which has been even more widely recognised amid the current crisis and high energy prices. The next chapter touches on the role of low-carbon fuels with a special focus on hydrogen, bioenergy and ammonia, which are the driving force behind accelerated clean energy transitions. Chapter 5 discusses the issue of existing fossil fuel infrastructure and the role of repurposing today's sites to maintain dispatchable generation. Efficient and economic clean energy transitions entail not only optimising the usage of fossil fuel infrastructure, but also addressing the possibility of transforming existing assets for other uses. The final chapter evaluates the role of critical minerals in clean energy transitions. The security of their supply, production and availability will be fundamental for accelerating clean energy transitions.

G20 economies are the drivers of global economic recovery as well as finance and investment. In the current high fuel price environment, governments need to rely on what worked well, quickly scale up such best practice policies, and avoid locking in new high-carbon infrastructure.

The focus of this year's Indonesia G20 Presidency is on the near-term actions up to 2030, with three core priorities. Indonesia looks to make progress in reaching universal energy access by 2030, scaling the deployment of clean energy technologies and increasing finance and investment, while employing an inclusive approach for the society at large and developing economies in particular.

The elements discussed in this report address a number of the issues created by the global energy crisis, but cannot address all of them. More will emerge and need to be solved as clean energy transitions accelerate, and the international community, including the G20, will continue to tackle them to achieve the goal of a net zero energy system. Enhanced international collaboration on energy security as part of clean energy transitions is, and continues to be, at the heart of the G20.

1. Prioritising energy efficiency in emerging economies

Energy efficiency is central to achieving affordable clean energy transitions that ensure equitable social development and economic growth. Decisive, ambitious and transformative action on energy efficiency is needed to improve the resilience, security and reliability of our energy systems, and improve access to sustainable and affordable energy services.

Without the efficiency improvements made since 2000, the world would be using 13% more energy today and energy-related carbon emissions would be 14% higher. Over half of the energy savings achieved can be attributed to efficiency measures in the industrial sector, about a third to efficiency in buildings and appliances, and a tenth to transport efficiency.

These efficiency improvements have lowered energy bills for households and businesses, enhanced competitiveness and supported job creation. Efficiency progress is also enhancing energy security and access to affordable, reliable energy. By cutting down overall energy demand, efficiency can significantly reduce overall reliance on fossil fuel imports, improve the balance of payments and reduce the likelihood of supply disruption. Efficiency gains since 2000 avoided the need for over 11 EJ of fossil fuel imports into IEA countries and other major economies[1] in 2017, equivalent to 20% more. Avoided oil imports into IEA countries alone were worth more than USD 30 billion.

Looking towards a net zero emissions future by 2050, there is still significant untapped potential: doubling the current rate of energy intensity improvement from 2% to 4% per year until 2030 has the potential to avoid 95 EJ per year of final energy consumption – equivalent to the People's Republic of China's (hereafter, "China") current final energy demand. Achieving 95 EJ of annual energy savings by 2030 would also translate into significantly strengthened energy security, avoiding the demand for almost 30 million barrels of oil per day, about triple Russia's average production in 2021, and 650 bcm of natural gas per year, around four times EU imports from Russia in 2021.

The actions outlined in the IEA 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas, the 10-Point Plan to Cut Oil Use and Playing my part: How to save money, reduce reliance on Russian energy, support Ukraine and help the planet show the power of energy efficiency to reduce reliance on fossil fuel imports through behaviour changes. If all EU citizens were

[1] IEA countries plus China, India, Brazil, Indonesia, Russian Federation, South Africa and Argentina.

to follow the recommendations at home and in their workplace, it would save 220 million barrels of oil a year and around 17 bcm of natural gas.

Reductions in electricity demand can also avoid the need for investment in new generating capacity, as well as in the required transmission and distribution infrastructure and storage facilities. In emerging economies, efficiency gains are particularly important to ensure the reliability and quality of energy supply services, to allow currently suppressed demand to come online without overstraining existing electricity networks, and to allow economic development. Achieving multiple benefits from action on energy efficiency is particularly important in the context of rising and fluctuating energy prices, which disproportionally hurt the most vulnerable segments of the population, and the economies of developing and emerging economies. People-centred and inclusive approaches and the prioritisation of energy efficiency are means to boost affordability and ensure that we are not reversing progress towards universal access to electricity (see also IEA (2021), Recommendations of the Global Commission on People-Centred Clean Energy Transitions). The Covid-19 crisis put an end to several years of continued progress and worsened the already low energy purchasing power of households in developing countries. In sub-Saharan Africa, the number of people without access increased in 2020 for the first time since 2013. The region's share of the global population without access to electricity rose to 77%, from 74% before the pandemic.

Following the pathway set out in the IEA Net Zero Emissions by 2050 Scenario (Net Zero Scenario), the global economy could grow by 40% by 2030 and support around 800 million more people with access to electricity, all with a 5% lower final energy demand. Compared to the IEA Stated Policies Scenario, energy efficiency and related measures in the Net Zero Scenario would reduce annual CO_2 emissions by 5 Gt in 2030. Over 80% of these additional efficiency gains result in overall net cost savings to consumers, helping to lower energy bills and cushion the effects of price volatility. Achieving 95 EJ of annual energy savings could contribute to lowering household energy bills by at least USD 650 billion per year by 2030.

This calls for strong and early action on energy efficiency by 2030. Governments play an essential role in ensuring the necessary front-loading and prioritisation of energy efficiency action. Recognising the value of early action on energy efficiency as a means of cost-effectively accelerating progress towards net zero energy targets, and increasing energy security and resilience, over 20 governments at the 7th IEA Annual Global Conference on Energy Efficiency signed a joint statement calling on all governments and other actors to strengthen their action.

Taking urgent action on energy efficiency

Recommendations from the Global Commission for Urgent Action on Energy Efficiency call for well-designed and comprehensive policy packages with ambitious targets, clear implementation strategies and strong monitoring frameworks. These policy recommendations can be implemented quickly and in different contexts to boost efficiency improvements globally, improve energy security, offset increasing energy demand and curtail CO_2 emissions growth.

To maximise impact in both the short and long term, existing best practice policies, cost-effective technologies and sustainable business models need to be scaled up quickly, drawing on knowledge of what has worked and what has not. Governments have a significant role to play in this transition, not only in leading by example but also as significant final consumers of energy services. Governments can lead this process by implementing whole-of-government approaches that align priorities and actions, thereby capturing all the benefits of energy efficiency and achieving greater impacts. For example, due to its high importance for overall energy consumption and quality of life, energy-efficient cooling is driven by whole-of-government national action plans in India and China.

The greatest efficiency gains are achieved by comprehensive policy packages that include a mix of regulation, information and incentives, while enabling innovation, investment and digitalisation.

Using regulation such as minimum energy performance standards to exclude the worst-performing appliances, equipment, vehicles and buildings from the market and to drive up average efficiency levels has led to the greatest improvements in efficiency historically. This concerns cooling and lighting in particular. By 2050 around two-thirds of the world's households could have an air conditioner, and China, India and Indonesia together account for half of the total number.

Regulation can be supported by bulk procurement programmes, such as the UJALA (Unnat Jyoti by Affordable LEDs for All) programme for 350 million LED bulbs in India, helping technologies become more affordable and accessible. These initiatives speed up the replacement of old inefficient technologies. Governments can lead by example through green procurement rules and specifications like those implemented in the European Union, which set minimum energy and environmental standards for buildings and government procurement. The US Federal Energy Management Program, as a further example, sets energy and water-reduction goals for federal agencies, and supports implementation by providing guidance, training and technical assistance. In Indonesia, government regulation 70/2009 requires all companies with an annual energy consumption exceeding 6 000 tonnes of oil equivalent to appoint an energy manager, develop an energy conservation plan, perform an energy audit and report energy consumption to the government. Discussions about lowering the industry threshold to 4 000 tonnes of oil equivalent and introducing sector-specific thresholds are underway.

Conducting comprehensive stakeholder engagement and leveraging behavioural insights can ensure that efficiency programmes are based on the actual needs and behaviours of end users, and also appropriately consider vulnerable groups. Energy efficiency policies that incorporate behavioural insights in both the design and implementation stages have proven to be more effective, as seen in the strengthening of the EU appliance energy labels. Putting people at the core of these policy actions and making better information available with the right narratives can have far-reaching impacts on the public attitudes and beliefs that drive consumption and mobility patterns – and can catalyse the much-needed behaviour change. Furthermore, redesigning policies and products to make energy savings the default option simplifies consumer choices. India has mandated that the default set-point temperature of room air conditioners be set at 24°C, which still leaves consumers with the free choice of temperature but achieves savings by default – through many consumers simply never changing the settings.

Governments can also incentivise efficiency improvements through financial mechanisms such as direct stimulus funding, investment in public buildings, facilities and infrastructure, preferential finance, public procurement with minimum requirements and market-based mechanisms. Efficiency action can be rapidly scaled up by boosting demand for efficient products and services through a range of financial and non-financial incentives, and by enabling greater levels of market activity through supply-side incentives such as finance or tax benefits for manufacturers. Standards and labelling, and dedicated end-user incentives for equipment replacement are effective examples. The replacement of 1 million inefficient refrigerators in Colombia, for instance, lowered energy bills for consumers, reduced the need for subsidies to low-income households and created 12 000 jobs.

Other options include enhancing industrial efficiency through targeted fiscal incentives or large-scale programmes that can combine a range of policy measures. India's Perform, Achieve, Trade (PAT) Scheme offers a market-based approach to driving energy efficiency investment. PAT is a multi-cycle programme to reduce specific energy consumption in the most energy-intensive industries by setting consumption targets and enabling businesses who beat their target to trade the Energy Saving Certificates (ESCerts) that they are issued with.

Implementation of energy efficiency policies and programmes needs to take place at all levels of society, and at national and sub-national levels, to maximise impact. For example, to enhance energy efficiency in buildings, local governments in Mexico and India developed the implementation action required to achieve national standards. Policy packages need to ensure that resources are available to turn policies into action, address the requirements for effective implementation (such as capacity building, enforcement and monitoring), and continually review and update policies and programmes to keep up with technological developments and innovation.

Energy efficiency can rapidly create sustainable employment and support economic growth for the long term. The IEA Sustainable Recovery Tracker highlights how economic stimulus programmes (in response to the Covid-19 pandemic) in key sectors quickly boosted economic activity, supported the existing workforce through upskilling and reskilling initiatives, and created new jobs to support economic recovery. High job creation potentials exist in construction and manufacturing, with key opportunities in building retrofits and technology replacement programmes. Drawing from international experience, the Make in India and Made in China programmes focus on creating high-quality manufacturing jobs through training and capacity building, while at the same time improving appliance efficiency and therefore making them more affordable for end users.

International collaboration can assist governments to implement energy efficiency policy more rapidly and effectively. The broad exchange of best practices allows countries to share and learn about successful and unsuccessful approaches to instilling energy efficiency in their economies. Of note is the Energy Efficiency Hub, a platform for global collaboration on energy efficiency.

Mobilising finance

Mobilising finance is essential to scale up efficiency action, and investing in energy efficiency is one of the cheapest ways to ensure energy security and affordability. While energy efficiency policies and technologies are well understood, current levels of investment are still too low. The IEA World Energy Investment 2022 report estimates that clean energy investment, standing at USD 1.3 trillion in 2021, has to more than triple by 2030 to around USD 4.5 trillion globally to put us on a net zero emissions pathway. Annual capital spending in emerging and developing economies has to increase sevenfold from current levels of about USD 200 billion to above USD 1.4 trillion.

Globally, total energy efficiency investment stood at about USD 330 billion in 2021, up by more than 25% from the previous year as the world emerged from the Covid-19 pandemic. The upscaling of existing government efficiency programmes and performance standards, combined with strong economic recovery, supported energy efficiency investment in the buildings and transport sectors in particular. However, rising costs, interest rates and supply chain shortages represent looming risks to the world's ability to maintain similar investment levels in 2022.

As of October 2021, efficiency-related spending made up two-thirds of new clean energy recovery spending, allocating 55% to transport, 30% to buildings and 10% to industry measures. Nonetheless, economic recovery spending is concentrated in a few advanced economies, and much of the developing world faces a significant financing gap to meet the levels of funding outlined in the IEA Sustainable Recovery Plan.

Policies to unlock financing have proven to be most effective when they combine measures in a coherent policy package that centres on driving larger-scale activity. They bring together policies to increase demand for efficient products and services with actions that reduce barriers to investment and enable appropriate and accessible finance and business models. Instruments to mitigate project risks and strengthen investor confidence include standardised documentation, product lists, third-party validation of achieved savings, capacity building and information campaigns, energy savings insurance and the support of energy service companies in the mobilisation of finance.

Direct public financing through grants and loans is particularly important to create short-term impacts and to support energy efficiency in critical areas like healthcare, vulnerable communities and social housing. Short-term financing could be most effectively applied by optimising and expanding existing financing mechanisms to reduce administrative costs and shorten lead times.

Many emerging and developing economies are more reliant on public sources to finance energy efficiency and energy access. To scale up financing in line with the Net Zero Scenario, special attention needs to be given to overcoming barriers to investment in these economies and to leveraging private investment. The IEA report Financing Clean Energy Transitions in Emerging and Developing Economies highlights that over 70% of clean energy investment is financed by private capital in the Net Zero Scenario, complemented and leveraged by the smart use of public funds. Investment in energy efficiency measures is typically done on a local level, and refinancing can be difficult in emerging and developing economies, which tend to have less mature domestic banking infrastructure and higher cost of capital than advanced markets. This can be a barrier for aggregators seeking to raise debt finance, particularly for small and medium-sized enterprises that form an important component of these economies. Local public or private green banks can act as aggregators of energy efficiency loan portfolios and seek cheap refinancing on capital markets to free up capital to invest in new projects.

The priority is to ensure the affordability of new and efficient equipment, appliances and vehicles, as well as the availability and accessibility of appropriate financing and payment options. Stricter performance standards, building certification schemes and wider deployment of financing solutions with preferential rates can support investment in green buildings and construction. Tax incentives and subsidies can encourage both the manufacture and uptake of efficient vehicles, while strategic planning frameworks and government grants for charging infrastructure and purchase incentives can enhance the uptake of electric mobility. The EU Energy Efficient Mortgages (EEM) initiative, for instance, aims to create a standardised energy efficiency mortgage that gives building owners the incentive to refurbish their buildings or buyers the incentive to acquire an efficient building through preferential financing conditions. The initiative introduces the EEM label as a quality benchmark to create trust.

Medium- to long-term financing approaches require government support in the form of technical and commercial de-risking, such as credit guarantees or energy savings insurance schemes, to attract private-sector investment. Lessons can also be drawn from successful guarantee schemes deployed for renewable energy, such as the World Bank's guarantee schemes or Argentina's RENOVAR auctions.

Governments can further incentivise efficiency investment by removing administrative barriers and supporting the expansion of existing private-sector financing instruments, such as on-bill financing linked to utility bills. Several governments in Europe have started to allow retrofit costs to be included in rental service charges to remove the classic split incentive between landlords and tenants – where the landlord pays for the capital investment and the tenant benefits from lower fuel bills. Market-based instruments, including utility obligation schemes and energy and carbon pricing mechanisms, can also stimulate demand and behaviour change. Energy service companies (ESCOs) can reduce upfront cost barriers to energy efficiency investment and act as project aggregators, thus achieving scale and lowering transaction costs.

Technical and financial support from international organisations and financial institutions can help emerging and developing economies make the necessary reforms to their financial and energy systems. The World Bank has played an important role in promoting China's ESCO market since 1998 by providing funding and technical assistance, including the establishment of a loan guarantee programme. In 2015, the Mexican government worked with the Inter-American Development Bank and the Clean Technology Fund to launch the Energy Savings Insurance (ESI) scheme, which used insurance mechanisms, standardised contracts and a simplified validation process to address energy efficiency project risks for the first time. The ESI programme was extended to seven other Latin American countries, including Argentina, Brazil and Colombia, and was featured in the G20 Energy Efficiency Investment Toolkit of 2017.

Recommendations

The following are the recommendations for the G20 countries to consider in their decision-making and policy implementation:

- **Rapidly scale up** existing best practice policies, cost-effective technologies and sustainable business models, **led by government.**
- Maximise impact by developing **comprehensive policy packages** that encompass a mix of regulation, information and incentives, while facilitating innovation, investment and digitalisation.
- **Adapt regularly standards and regulation to prevent** the least energy-efficient appliances, equipment, vehicles and buildings from being put on the market.
- Ensure that **efficiency programmes are based on the actual needs and behaviours** of end users and include vulnerable groups by conducting comprehensive stakeholder engagement and leveraging behavioural insights.
- Develop the underlying conditions to **enable effective implementation** of energy efficiency policies and programmes **at all levels**. Ensure that resources are available to turn policy packages into action, to enable effective implementation through capacity building, enforcement and monitoring, and to continually review and update policy packages so they keep up with technological developments and innovation.
- Create policy packages to **unlock financing**, encompassing measures to increase demand for efficient products and services, reduce barriers to investment and enable innovative business models and accessible financing mechanisms.
- Gradually shift the focus from providing direct public financing for short-term impacts to **leveraging and de-risking private-sector financing** for energy efficiency.
- Scale up international collaboration on energy efficiency to assist governments to implement more rapid and effective energy efficiency policies.

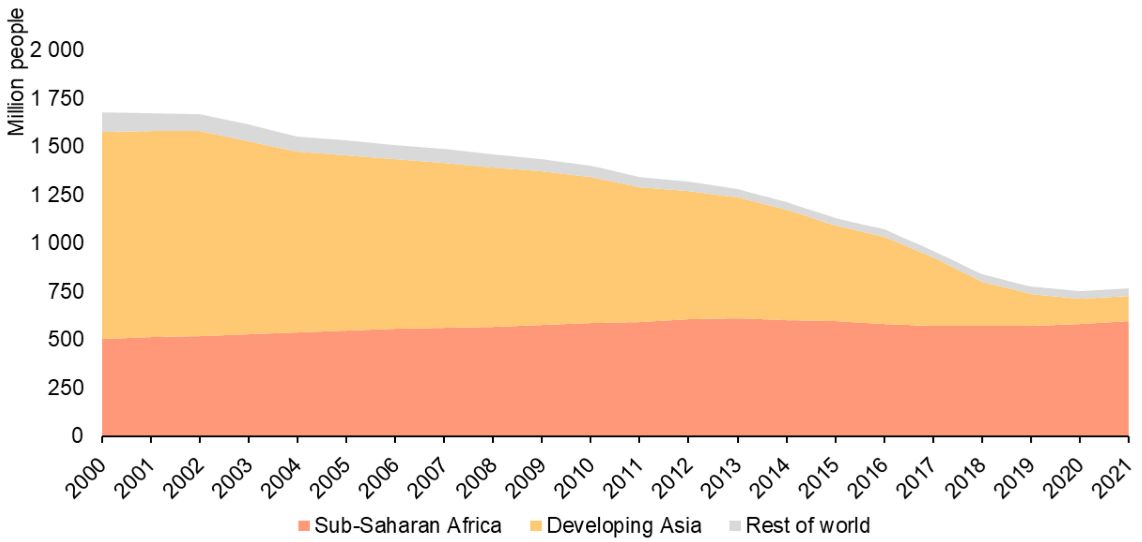
2. Boosting access to affordable and reliable electricity

Growing electricity demand and electrification

Electricity plays a growing role in all economies and its share of total energy demand is expected to grow universally under the impetus of improving living standards and electrification of end uses.

The need to expand access to affordable and clean energy to all citizens, in line with the United Nations' Sustainable Development Goal 7 (SDG7), continues to be a critical driver of electricity demand growth. As household incomes increase, more appliances are connected and electricity demand rises. While emerging economies are on track to achieve universal access by 2030, developing economies in sub-Saharan Africa and developing Asia are at risk of not meeting the target (figure below).

Global population without access to electricity by region, 2020-2021



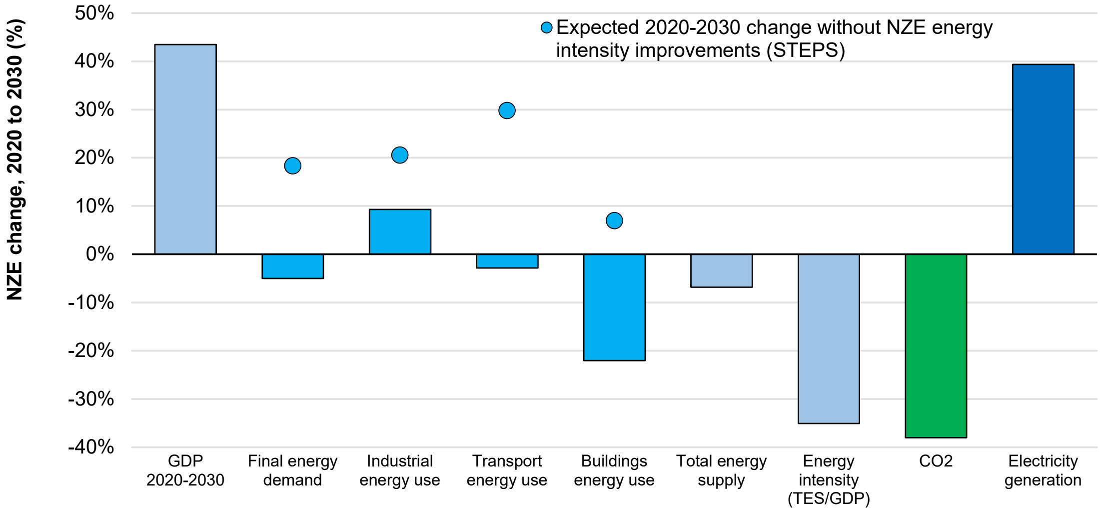
Source: IEA (2021), The pandemic continues to slow progress towards universal energy access.

As a whole, the world is therefore not on track to meet the goal of universal access to electricity by 2030, as the Covid-19 pandemic and the energy crisis provoked by the Russian invasion of Ukraine have slowed progress. At current rates, the world will reach only 92% electrification by 2030. The world must accelerate progress, as 770 million people globally still lack access to electricity, most of them in sub-Saharan Africa, as illustrated in the figure above, based on the latest IEA Tracking SDG7: The Energy Progress Report 2022.

In advanced economies, after years of stagnation, electricity demand is rising again, with road transport and heating preparing the major shift away from fossil fuels to electricity.

In the IEA Net Zero Emissions by 2050 Scenario (Net Zero Scenario), energy intensity is improved in all end uses, particularly in buildings, thanks to energy efficiency, behaviour change and electrification. In contrast, electricity generated grows by nearly 40% between 2020 and 2030.

Key energy and economic trends in the Net Zero Scenario pathway, 2020-2030



Notes: GDP = gross domestic product; NZE = Net Zero Emissions by 2050 Scenario; STEPS = Stated Policies Scenario; TES = total energy supply.

Renewables’ contribution to supply diversification

The central role of electricity in modern economies means that the transformation of the power system requires more attention from policy makers to sustain energy security, notably maintaining and improving the quality and affordability of supply during the transition.

Electrification and the deployment of renewables help reduce the energy system’s carbon footprint and dependency on – often imported – oil products, natural gas and coal. For electrification to become the backbone of clean energy transitions, efforts to move to net zero emissions in electricity generation should be a key priority.

As we decarbonise our electricity systems, the share of variable renewable energy (VRE), particularly wind and solar, will increase as they become increasingly competitive with other generation technologies. The IEA showed in its recent Southeast Asia Outlook that the share of VRE in the region's electricity could increase from 2% in 2020 to 18% in 2030. In the IEA Net Zero Scenario, nearly two-thirds of global electricity is provided by wind or solar in 2050.

The current global energy crisis has added new urgency to accelerating clean energy transitions and, once again, highlighted the vital role of renewable energy. The world added a record 295 GW of renewable power capacity in 2021. Furthermore, despite the increased cost of installing solar PV and wind turbines due to high commodity prices and continuing supply chain and logistical challenges, renewable capacity additions are set to mark another record this year – 320 GW of new installations – driven by the unprecedented expansion of solar PV. This total for 2022 comes close to being the equivalent needed to meet the entire electricity demand of Germany or match the European Union's total electricity generation from natural gas. This proves not only the essential role of renewables in reducing emissions, but also their capability to contribute to energy security by substituting gas use in the power sector.

As a result of their strong growth, renewables are contributing to the diversification of the energy supply in many world regions, which is an important element of energy security. In addition to China maintaining its global lead, record growth is also being driven by strong renewable energy targets and consistent policies in Europe, India, Latin America and the Middle East and North Africa.

Renewables increase energy security not only by avoiding the use of fossil fuels and by diversifying supply, but also by lowering costs and thereby increasing affordability. Although the cost of installing solar PV and wind turbines is expected to remain higher in 2022 and 2023 than before the pandemic, due to elevated commodity and freight prices, their competitiveness is actually improving due to much sharper increases in natural gas and coal prices.

Nonetheless, stronger policies are still needed to support the growth of renewables. Accelerating the permitting process and providing the right incentives for more rapid deployment – for all renewables including flexible hydropower – are some of the most important actions governments can take to address today's energy security and future climate goals.

The strong growth of variable renewables in electricity systems calls for a diversified mix of resources to fulfil the need for essential system services, such as flexibility,[2] which outpaces the increase in electricity demand.

Market frameworks should value services needed for secure system operation

In light of increased penetration of resources that are not flexible or dispatchable, particularly VRE, governments need to adjust energy market frameworks in order to procure all system services needed for secure power system operation, including adequacy, flexibility and stability at lowest cost. The right market framework can activate resources when and where they are needed, from low-carbon dispatchable capacity (such as hydropower and geothermal), demand response, batteries, grids and greater interconnections across isolated electricity systems. In addition, zero emission thermal generation running on lower-carbon fuels such as hydrogen and ammonia, provides key flexibility for expanding renewable energy.

To maintain adequate capacity, particularly from resources that might only be required to run infrequently, regulators should consider scarcity pricing in energy markets and capacity remuneration mechanisms. These measures, together with the lifetime extension of nuclear power plants, should prevent the premature retirement of resources that could be used to support the secure operation of the power sector, as was seen in some markets, particularly Japan but also Texas.

Electricity security is a cross-sectoral matter and benefits from diversification

Secure power systems also require secure fuel supplies to be able to feed the generation fleet. In many countries, gas-fired power plants are playing the critical role in covering peak demand periods and providing the flexibility to accommodate larger shares of wind and solar generation. As the world recovers from the Covid-19 pandemic and has to deal with the impacts of the Russian invasion of Ukraine, global gas markets have become very tight. This has had significant spillover effects on electricity systems dependent on gas. In many emerging economies, notably in Asia Pacific and Latin America, liquefied natural gas (LNG) supplies are the main source of flexible gas supply in the absence of pipelines and underground gas storage, which brings additional costs and supply risks. Coal-fired power generation is still the backbone of power supply in many Asian countries. However, inflexible fuel contracts and changing generation economics could leave

[2] Power system flexibility refers broadly to all the attributes of a power system that allow the system operator to reliably and cost-effectively balance demand and generation in response to variability and uncertainty.

coal-fired generation as the only source of system flexibility, which threatens climate goals unless related emissions are mitigated (see Chapter 3).

The war in Ukraine further stressed the dependency of the global economy on imported fossil fuels and the lack of diversity in supply chains, giving urgency to the need for an accelerated energy transition and a commitment to a more diverse portfolio of clean electricity. Despite the unique characteristics of the current crisis, it is a warning of the higher risk involved when economies heavily rely on a dominant fuel type or supply channel.

Energy system integration requires stronger co-ordination across sectors and among stakeholders, both in planning and operations. Power system planning needs to identify the investment required to ensure security of supply in the decades ahead. Integrated and co-ordinated planning frameworks – which should cover generation, transmission and distribution networks, demand, the electrification of end uses and dependencies on other sectors – become essential to identify appropriate options for the future power system, in the light of demand and technology uncertainty. Such integrated planning can help identify the need for interconnections at the national, regional and international level. And despite the trend towards decentralisation, secure interconnected power systems are the backbone of our societies. Regional trade is a key source of flexibility in Europe and the United States, while the Association of Southeast Asian Nations (ASEAN) countries are working on greater interconnectivity and trade. Indeed, the IEA is working with ASEAN to boost multilateral power trade in the region (see Establishing multilateral power trade in ASEAN – IEA Analysis and Southeast Asia Energy Outlook 2022 – IEA Analysis).

Affordable and reliable supply

The extent and quality of people's engagement in clean energy transitions will determine their support for the measures and deployment of infrastructure required to achieve climate goals.

To start, greater reliance on clean electricity systems cannot come at the expense of affordability. As such, governments need to consider the cost of power system transformation and ensure a fair distribution of this cost to ensure that low-income or vulnerable customers do not bear outsized burdens as a result of the energy transition. Energy efficiency can play a crucial role in this regard, in concert with electrification strategies, to affordably achieve emission reductions, as described in Chapter 1.

Transformation of the electricity system will not only have implications for reliability and affordability, but can also lead to major changes in the siting of a country's electricity generation facilities and associated economic and employment configurations. Wind and solar resources are not always located where traditional mines or coal-fired units have supplied electricity to regions for decades. When traditional fossil assets are phased out, governments should also ensure that workers and communities that are negatively impacted by closures have opportunities to participate in economic revitalisation plans and are offered necessary retraining and upskilling to find new jobs, with sufficient funding made available to ensure a smooth transition.

Another way to engage citizens is to enable them to play an active role in the energy transition. The declining cost of small renewable supply units and digital technologies can foster active consumers and local energy communities. This decentralisation trend empowers citizens, raising awareness of the time and locational value of energy resources, and is an opportunity for people to play a more active role not just in energy transitions, but also in providing electricity security.

Demand elasticity is expected to increase as consumer behaviours change and demand-side response becomes a resource, valued equally to generation, if not more so thanks to its fast reaction to prices. The recent record-high prices on global energy markets across all fuels, however, also highlights the need to protect vulnerable consumers and to ensure proper regulatory oversight of market participants and tariffs to ensure a fair distribution of costs and gains between stakeholders, including between those users who can invest in the means to capture market benefits and those who cannot.

Despite growing access to electricity, the quality of supply often remains unreliable or of poor quality for many households and businesses. This is a barrier to lifting people out of poverty and enabling economic development. Governments must lead efforts to provide access to a secure, affordable and clean electricity supply. They can start by making sound plans in co-ordination with all stakeholders and allocating appropriate responsibilities and incentives to all relevant organisations in their jurisdictions.

Universal access will be made possible through the subtle combination of conventional connections to large grids, partially autonomous local grids, and isolated systems. Plans must therefore span the complete range of solutions, from master plans for rural electrification to integrated plans to expand and reinforce large grid infrastructure. In turn, these plans will provide clear signals for financing the necessary investment, which is currently lagging behind what is needed to stay on the pathway set out in the IEA Net Zero Scenario.

Good alignment between clean energy transitions and electricity access policies can enhance the success of both. A number of programmes have successfully reduced energy bills for low-income households while also expanding access to clean energy. Several countries are moving closer to universal electricity access by installing solar home systems in the most remote, hardest-to-reach systems, thereby "leapfrogging" to off-grid solutions.

Electricity security is more important than ever and requires risk-based, integrated approaches

Electricity security is often defined as the system's ability to ensure uninterrupted availability of electricity; simply said, it is "keeping the lights on", and entails ensuring adequacy under a wide range of conditions. Past practices focused on ensuring the adequacy of the supply system (generation and grids) to meet an uncertain and variable demand and the flexibility to cope with a relevant set of outages. With the growth of wind and solar generation, the paradigm is shifting as generation becomes more variable and demand can become part of the solution. The number of unknowns has grown and adequacy studies need to acknowledge growing uncertainties. Probabilistic adequacy assessments give greater insight for systems with a high share of renewables as they allow many uncertainties to be evaluated together.

Recent extreme weather events across the globe highlight the energy security risks that climate change brings. In particular, rare events with potentially large consequences ("tail risks") must be considered. Adequacy must be ensured under a wider range of conditions. In planning studies, "stress tests" must be included that assume extreme weather events or failures due to growing cybersecurity threats. These studies should also be designed to aid decisions on whether assets meant to be retired should be kept on in order to mitigate risk in "low-probability high-impact" scenarios. Policy makers must require regular adequacy studies and review the criteria used in them to ensure all relevant outage risks are captured.

Power systems are digitalising, bringing benefits at all levels, from the management of generation and grids to the rise of new capabilities and services from a wider set of resources, including the demand side. Digitalisation, however, comes with increased cybersecurity risks. A successful cyberattack could trigger the loss of control over devices and processes, in turn causing physical damage and widespread service disruption to electricity systems. A wealth of cyber-risk management tools and frameworks have been deployed and policy makers play a central role in selecting and implementing them.

Whether physical or cyber, not all events can be prevented at reasonable cost, requiring a risk-based approach. Policy setting and planning can be seen as an iterative process: the policy goals are key inputs to planning and, in turn, the planning exercises provide essential information on the options and corresponding costs to meet the policy objectives. The selected trajectory must strike a balance between the deployment of (costly) preventive measures and the consequences of various incidents occurring, ranging from expected outages to rare events. In their effort to strive for affordable and secure power, policy makers should aim for a higher resilience, that is the ability of the system to absorb, accommodate and recover from short-term shocks (supply crisis, cyberattack or extreme weather events) and long-term, more gradual changes (adaptation to evolving needs and weather patterns).

Risk-preparedness plans help identify cost-effective resilience measures: for instance, greater diversity in the resource mix can ensure resilience against social, geopolitical, market, technical and environmental risks. For most countries, the shift away from imported fuels supports the resilience and the sustainability of the power system. With a deeper understanding of the risks, governments and regulators are equipped to design appropriate incentives for utilities to invest in a resilient power system in a timely manner.

Recommendations

The following are the recommendations for the G20 countries to consider in their decision-making and policy implementation:

- **Provide longer-term visibility** of policies affecting the power sector, including visibility for energy system integration needs and **allocate responsibilities and incentives** to all relevant organisations to ensure proper co-ordination across all time ranges, from system planning to operations.
- **Ensure robust and inclusive planning approaches**, such as integrated and co-ordinated planning frameworks.
- **Engender a people-centred mindset**: ensure a fair redistribution of costs and benefits so that vulnerable consumers are supported, safeguard universal access and support local transition plans for workers and communities impacted by power plant closures.
- Adopt **a risk-based approach** to system security: understand all the dependencies of the power sector now and in the future, assess the related risks and deploy risk-preparedness plans with appropriate indicators that are monitored and periodically reviewed.
- Support **the resilience of power systems** by shifting away from imported fossil fuels and – starting with energy efficiency – by promoting diverse, clean power solutions that are adapted to local circumstances while paying attention to growing threats such as climate change and cybersecurity.

3. Preparedness and response to global energy crises

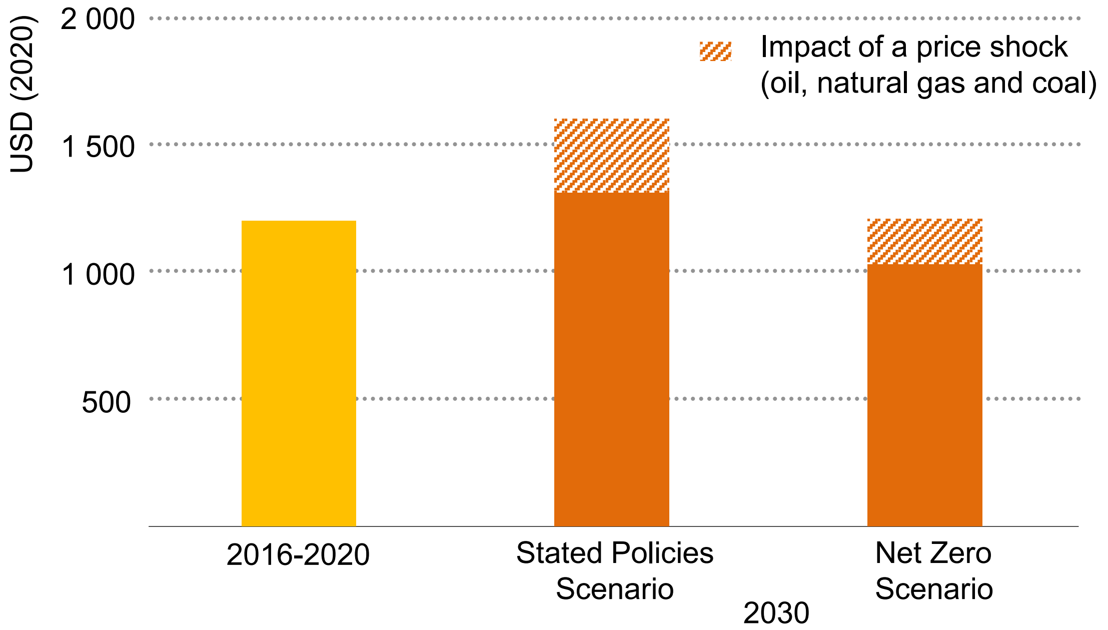
Traditional energy security risks related to oil and gas supply have been back in the spotlight due to rapid economic recovery after the Covid-19 pandemic and Russia's invasion of Ukraine.

While energy transitions raise new challenges to energy security, traditional supply security risks linked to fossil fuel use, notably oil and gas, continue to play an important role in ensuring sufficient energy supply. It should be noted that demand for oil and gas is recovering robustly and this trend is expected to continue, even during clean energy transitions, far above the path required to achieve net zero. But energy security is evolving, and the extent and type of risks to energy supplies are broadening, requiring countries to anticipate and manage both existing and newly emerging energy security challenges. Accelerated transitions are likely to amplify both old and new security factors, requiring the bolstering of resilience and emergency response capacities to ensure the uninterrupted flow of affordable energy.

Emerging and developing economies, working jointly under the G20 and in other regional fora such as the ASEAN and the Asia Pacific Energy Research Centre (APERC), can share experience and work together on effective preparedness, including at regional levels and collectively, involving consumers and producers.

An important dimension of clean energy transitions is how they are perceived by consumers in terms of security, reliability and affordability. Price increases can have a disproportionate impact on the most vulnerable consumers, potentially exacerbating poverty and inequality (see figure below). Clean energy transitions can cushion consumers from the shock of spikes in oil and gas prices if households can get help to manage the upfront costs of energy efficiency improvements and electrification. Therefore, it is imperative that clean energy transitions are undertaken in ways that ensure stability in energy supply and prices.

Impact of a price shock on average household energy bills, 2016-2020 and 2030

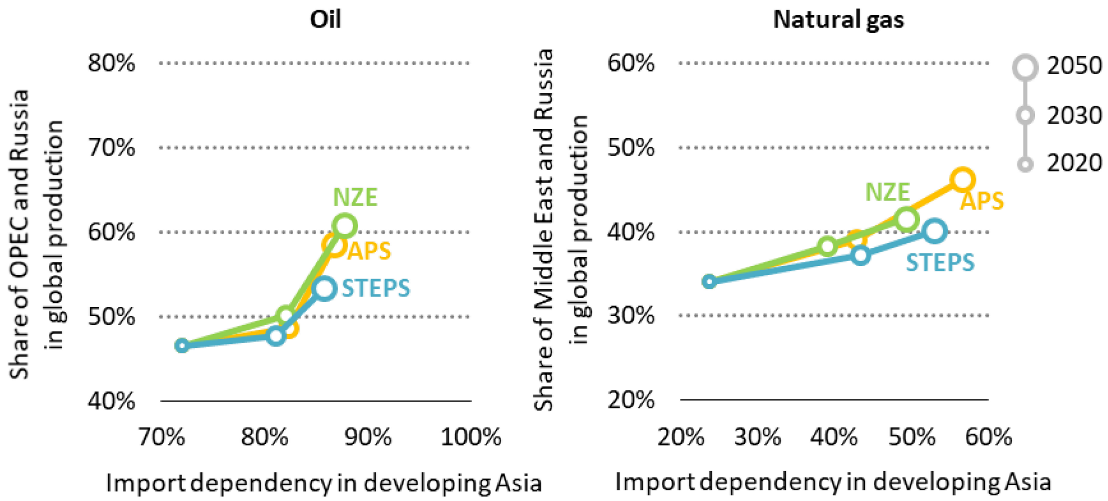


Source: IEA (2021), adapted from World Energy Outlook 2021.

Oil and gas remain significant during energy transitions

Oil and gas consumption will remain important during the transition. Even under the IEA Net Zero Scenario, the dependency of developing Asia on oil and gas imports remains high, notably on OPEC+ supplies.

Import dependency in developing Asian economies and supply concentration for oil and natural gas by scenario, 2020-2050



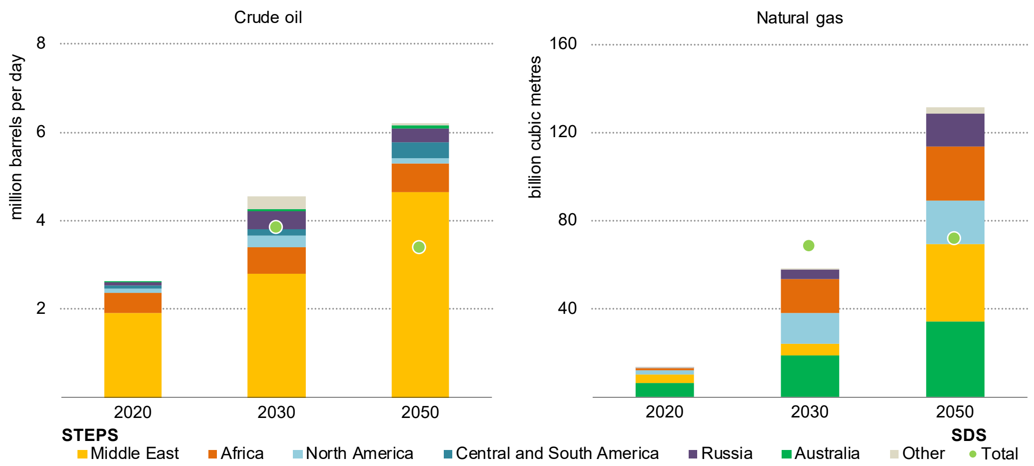
Notes: APS = Announced Pledges Scenario; STEPS = Stated Policies Scenario; NZE = Net Zero Emissions by 2050 Scenario.

Source: IEA (2021), World Energy Outlook 2021.

As highlighted in the IEA report Net Zero by 2050: A Roadmap for the Global Energy Sector, crude oil production is likely to become increasingly concentrated in a smaller number of oil producing countries, mainly in the Organization of the Petroleum Exporting Countries (OPEC) members, while global refining capacity additions will be concentrated in the Middle East and Asia. As global oil demand declines, the IEA expects OPEC to increase its market share of global oil production to 52% by 2050, compared with 37% in recent years. This concentration of production could potentially limit oil importing countries' efforts to diversify supply, which in turn could have a negative impact on energy security.

Similarly, the IEA Southeast Asia Energy Outlook 2022 illustrates the increasing oil and gas trade volumes between the Middle East and Southeast Asia.

Crude oil and natural gas sales to Southeast Asia in STEPS by origin, and in SDS in total, 2020-2050



Notes: SDS = Sustainable Development Scenario; STEPS = Stated Policies Scenario.
Source: IEA (2022), adapted from Southeast Asia Outlook 2022.

The case for developing an oil stockholding regime and introducing or strengthening gas storage systems

Oil will remain relevant during the energy transitions and oil supply security concerns will not fade away even as its use is phased out. On the contrary, there is a potential for heightened market volatility, particularly if reductions in demand are outpaced by decreases in supply due to lack of investment, or if remaining supply is concentrated in fewer countries.

The IEA has an oil stockholding requirement which obligates its member countries to ensure oil stocks of at least 90 days of net imports and has a mechanism to take collective action in case of oil supply disruption. The IEA collective actions that took place in March and April 2022 are examples of co-ordinated international measures to address oil supply disruption against the backdrop of Russia's war on Ukraine, by which the 31 member countries of the IEA agreed to release well over 180 million barrels of oil from their emergency reserves. These actions have sent a strong unified message to global oil markets that IEA member countries are united in their support of Ukraine and will do all they can to provide stability to the market. These actions have also shown to the world that oil stockholding during energy transitions remains critically important to ensure a stable supply of oil, and is an invaluable tool to maintain oil security in case of oil supply disruption.

An evaluation of the current mechanism is vital to make sure that countries continue to be ready to respond to disruption during their energy transitions and with a greater concentration of oil consumption in emerging economies.

It should be noted that emergency oil stocks are as relevant to non-IEA member countries as they are to IEA member countries, particularly where oil consumption is growing. Oil storage or any mechanism to prepare for unexpected oil supply disruption would contribute to the enhancement of oil security at various levels – local, national and global. Emerging economies, including China, India, Indonesia and certain other ASEAN countries, have started to put oil stocks in place to mitigate risks stemming supply disruption.

As with oil stocks, gas storage could be a useful means to enhance security of gas supply to overcome unexpected gas supply disruption. With the increasing importance of gas as a transition fuel in many countries, and to address particular issues in certain countries (e.g. seasonal variations in demand), it is worthwhile for every country to consider introducing or strengthening measures and policies regarding gas storage. One policy option is to impose a minimum level of gas storage or to establish compulsory gas stocks. EU countries are implementing policies to impose minimum stock levels. Many emerging economies do not have underground storage and rely on LNG storage for peak shaving. Various measures could be implemented according to the country's situation, such as gas demand and weather condition forecasting (including seasonal trends). These measures need to be implemented with clear guidance from government with medium- or long-term strategies. In addition to measures taken by individual countries, regional co-operation could be pursued, where appropriate, to strengthen gas security.

Implementation of both supply and demand measures

The enhancement of energy security can be accomplished through various policy measures and actions. Governments tend to focus on supply-side measures. However, the acceleration of energy transitions cannot be achieved with supply-side measures alone, and governments also need to pursue demand-side measures to scale and speed up the transformation of their energy systems.

Given the notable behavioural aspects of demand-side measures and possible cost impacts, governments should explain carefully the necessity and importance of the measures to the public, raising public awareness of energy transitions.

In this regard, in March 2022 the IEA released a 10-point action plan with the European Union, containing a series of measures that could reduce Russian natural gas imports into the European Union by 50 bcm, or a third, within a year. Examples of supply-side measures are not signing any new gas contracts with Russia, maximising gas supplies from other sources, ensuring gas storage sites are filled ahead of the next winter, and lifting barriers in permitting procedures for the deployment of solar and wind. Energy efficiency measures, including insulation, appliance upgrades, smart metering and reducing the room temperature, can leverage huge energy savings, thus enabling lower natural gas consumption and imports. For example, heating thermostats in buildings across the European Union are currently set at an average of over 22°C. Lowering the thermostat by just 1°C would deliver immediate annual energy savings of around 10 bcm, while also bringing down energy bills.

The IEA 10-point plan on reducing oil demand in advanced economies also offers practical advice on how lower levels of demand can reduce market uncertainty and volatility. Actions include less business travel, working from home, using public transport, car-fee Sundays and several other measures. While the IEA actions focus on advanced economies, potentially leading to an estimated drop in oil demand of up to 2.7 million barrels a day, this amount could be even greater if adopted in emerging economies in the G20.

The need for adequate investment in infrastructure

The planning and development of adequate infrastructure, for oil imports and storage, for LNG imports, and for natural gas storage and distribution, are indispensable to ensure stable supply, particularly in energy importing countries, where demand for oil and gas continues to grow during energy transitions. Maintaining sustainable supplies and meeting growing demand during energy transitions require adequate levels of investment in infrastructure, and planning should be supported by medium- and long-term national strategies to avoid new infrastructure becoming stranded assets in the future.

Recommendations

The following are the recommendations for the G20 countries to consider in their decision-making and policy implementation:

- **Develop an oil stockholding regime** and **consider the enhancement of gas storage systems** that take account of changing supply and demand trends, accompanied by **adequate investment in infrastructure**, particularly in regions that will continue to experience demand growth.
- Encourage the widespread implementation of **supply- and demand-side measures identified in the IEA 10-point plans** across the G20 to address price volatility, fuel costs and supply shortages.

4. The role of low-emission fuels

Low-emission hydrogen

Low-emission hydrogen is expected to have a major role in clean energy transitions, notably in “hard-to-abate” industries. Its large-scale adoption will require a secure and affordable supply, which will necessitate the development of an efficient global market and resilient supply chains. Not all industries can be successfully electrified; this makes the widespread adoption of low-emission hydrogen a crucial element of any successful clean energy transition. The projected growth in low-emission hydrogen production in the coming years also provides an important opportunity to create new jobs and to reskill existing workforces. Low-emission hydrogen, and derivatives (including synthetic fuels) can also support mitigation of CO_2 emissions from shipping, aviation, and heavy-duty land transport.

The challenges surrounding the transitioning of existing natural gas infrastructure to handle low-emission hydrogen supply are discussed later in this report (see Chapter 5). This section discusses the challenge of developing interregional trade in low-emission hydrogen (and ammonia) to enable its global uptake at scale.

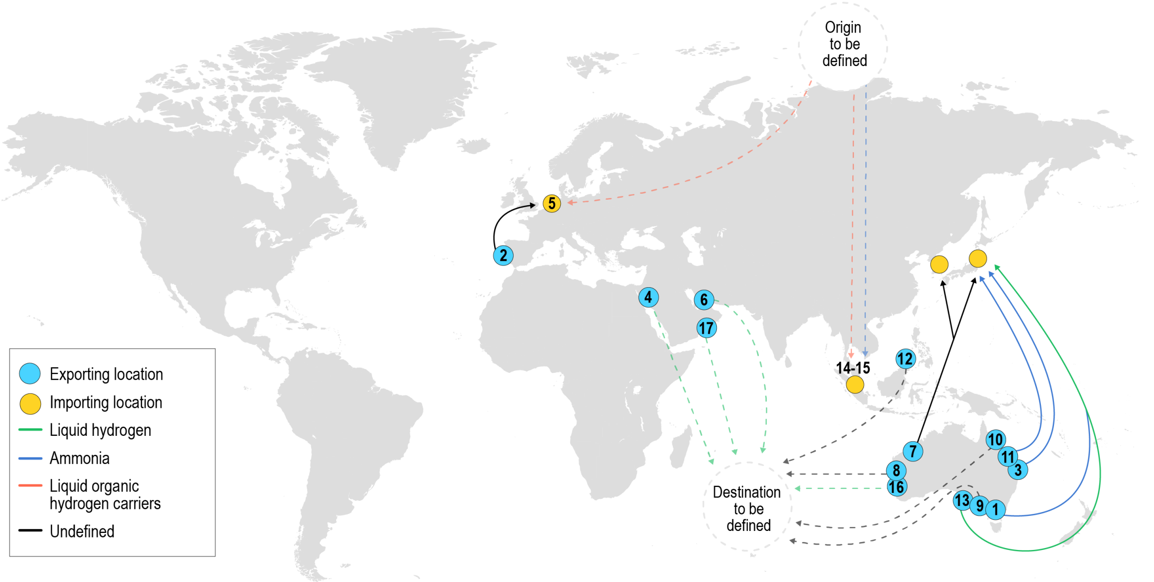
Trade in low-emission hydrogen is set to grow and supply chains are likely to develop, but for a secure, affordable and clean supply of low-emission hydrogen and to ensure that the supply chains are resilient, greater international co-operation is needed. A recent pilot project between Australia and Japan serves as a good example, in which Australia shipped liquid hydrogen to Japan via a specially built carrier. In Southeast Asia, Brunei Darussalam has started exporting small quantities of hydrogen to Japan.

In the region, Indonesia, Malaysia, the Philippines and Thailand are piloting green hydrogen and fuel cell systems for domestic power provision. Malaysia Indonesia and India are conducting feasibility studies to co-fire ammonia in coal power plants, and there are plans to do so in Singapore, Thailand and Viet Nam.

Currently, more than 100 projects aiming to trade hydrogen (or its derivatives, such as ammonia and synthetic fuels) are under development around the globe, with about half of them based in the South East Asia region. If all these projects are realised, the equivalent[3] of nearly 5 Mt of H_2 could be being traded by 2030. Adequate export and import infrastructure is needed to establish a global low-emission hydrogen market.

[3] Some of these projects are looking to transport hydrogen in the form of ammonia, synthetic hydrocarbon fuels or liquid organic hydrogen carriers.

Selected international hydrogen and ammonia trade projects



Note: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Source: IEA (2021), Global Hydrogen Review 2021.

Selected international hydrogen trade projects

Project	Export country	Import country	Volume	Carrier	Expected first shipping year	Map Reference
Hydrogen Energy Supply Chain	Australia	Japan	225 540 tpa	LH_2	2030	1
H2 Sines	Portugal	Netherlands	TBD	TBD	TBD	2
Stanwell - Iwatani Gladstone project	Australia	Japan	280 000 tpa	LH_2	2026	3
Helios Green Fuels	Saudi Arabia	TBD	650 tpd	Ammonia	2025	4
H2Gate	TBD	Netherlands	1 000 000 tpa	LOHC	TBD	5
ADNOC - TA'ZIZ industrial hub	United Arab Emirates	TBD	175 000 tpa	Ammonia	2025	6
Asian Renewable Energy Hub	Australia	Japan or Korea	TBD	LH_2 or ammonia	2028	7
Murchison	Australia	TBD	TBD	TBD	TBD	8
Crystal Brook Energy Park	Australia	TBD	25 tpd	TBD	TBD	9
Pacific Solar Hydrogen	Australia	TBD	200 000 tpa	TBD	TBD	10

Project	Export country	Import country	Volume	Carrier	Expected first shipping year	Map Reference
Origin Energy - Kawasaki Heavy Industries Townsville project	Australia	Japan	36 000 tpa	LH_2	2025	11
KBR SE Asia feasibility study	Southeast Asia	TBD	TBD	TBD	TBD	12
Eyre Gateway	Australia	Japan or Asia	7 000 tpa	Ammonia	TBD	13
Unnamed	TBD	Singapore	TBD	LH_2	TBD	14
Unnamed	TBD	Singapore	TBD	LOHC	TBD	15
Project Geri	Australia	TBD	175 000 tpa	Ammonia	TBD	16
Green Mega Fuels Project	Oman	TBD	175 000 tpa	Ammonia	2032	17
Western Green Energy Hub	Australia	TBD	34 000tpa	Ammonia	TBC	18

Notes: LH2 = liquefied hydrogen. LOHC = liquid organic hydrogen carrier. SE Asia = Southeast Asia. TBD = to be determined. tpa = tonnes per annum. tpd = tonnes per day.
Source: IEA (2021), Global Hydrogen Review 2021.

The supply chain for low-emission hydrogen is complex and still evolving, as several of the required technologies are not yet commercially available. Therefore, the development of a resilient supply chain will require ambitious actions on several fronts. Significant investment is required across the whole value chain, including upstream renewable energy capacity, infrastructure for the transport and storage of hydrogen, and manufacturing capacity for key technologies such as electrolysers and fuel cells. Realising these investments requires an understanding of future low-emission hydrogen demand and the scale of production to de-risk them. For hydrogen production, low-carbon technologies are ready to be deployed at scale to produce hydrogen from electricity via water electrolysis or from fossil fuels in combination with carbon capture, utilisation and storage (CCUS). The necessary investment, however, is unlikely to occur unless project developers can rely on long-term offtake agreements. This, in turn, will require governments to adopt supporting policies to create demand for low-emission hydrogen, either to replace hydrogen produced from unabated fossil fuels in existing uses, such as fertiliser production and oil refining, or to replace fossil fuels in new applications, such as steelmaking, shipping and aviation. Many of the technologies required for these new hydrogen applications are still at the demonstration stage today. A strong focus on innovation is needed to ensure that these new technologies reach commercialisation soon.

Scaling up the deployment of hydrogen technologies, such as fuel cells and electrolysers, triggers the need to expand the supply chains for existing technologies and to develop supply chains for emerging technologies. Challenges associated with the supply of critical minerals are discussed in the following section in detail. But another important supply chain consideration is the expansion of manufacturing capacity for electrolysers, which is currently very limited and largely concentrated in a small number of companies, mainly located in Europe and China. Electrolyser manufacturers are responding quickly to the growing demand, with manufacturing capacity expanding faster than ever. However, practically all announcements for new manufacturing plants are still based in Europe and China, with some new actors in Australia, India and the United States gaining small market shares. Supplier diversification (both geographically and in the number of companies involved) can improve the resilience of supply chains by avoiding potential disruption and bottlenecks while ramping up technology deployment.

The development of infrastructure to convert, transport and store hydrogen is another critical step for the development of resilient hydrogen supply chains. Short-distance hydrogen transport is likely to be dominated by pipelines. The transport of hydrogen via pipeline is a mature technology, but it is capital-intensive, requiring high upfront investment. Converting existing natural gas pipelines to hydrogen can substantially reduce the cost, but the technical feasibility needs to be assessed individually for each pipeline or network, while regulations and technical standards may need to be adapted to allow for such a conversion.

Alternative options exist for long-distance transport, some at an early stage of development, which can create uncertainty in the choice of infrastructure type. One option is to transport hydrogen in liquefied form. However, hydrogen liquefaction occurs at a much lower temperature than for LNG and is an energy-intensive process, requiring further technological development to reduce the energy need and move the process from the smaller units deployed so far to large-scale designs. Using ammonia as a hydrogen carrier is another option, benefiting from existing experience in the fertiliser industry of shipping ammonia and handling it at ports. Regarding the toxicity of ammonia, this includes experience in handling it in a safe way. Where the reconversion of ammonia into hydrogen is needed at the final destination, this cracking process comes with additional energy needs and so far has not been demonstrated at the scale anticipated for hydrogen trade. The toxicity of ammonia also means that its handling requires care and would likely be limited to professionally trained operators. Finally, hydrogen can be transported using liquid organic hydrogen carriers (LOHCs), which have properties similar to crude oil and can make use of existing oil infrastructure. But the conversion of hydrogen into an LOHC and reconversion back into hydrogen come with additional energy needs and costs. Furthermore, after being used to transport hydrogen to its destination, the carrier needs to be shipped back, increasing the cost of this transport option.

Biomethane and biofuels

The main factors that are expected to influence biofuel demand in the coming years are oil prices, biofuel prices and how governments evaluate the role of biofuels in navigating energy security, food security and greenhouse gas objectives. Biofuel demand has recovered from Covid-19 lows, but increasing feedstock prices and policy reaction from multiple countries is slowing growth in the short term.

Bioenergy already makes important contributions to ensuring energy security and the resilience of the global energy system. Without it, the current situation would be much more difficult. As the world's largest renewable energy source, bioenergy adds to diversification, provides energy security and reduces market prices at the margin.

Bioenergy is also the most versatile form of renewable energy. It can deliver heat and power, supply fuels for transport or deliver renewable gas. One of its key advantages is that it can use existing infrastructure, which makes possible a rapid increase in multiple bioenergy end uses. For example, biomethane can use existing natural gas pipelines and end-user equipment, while many drop-in liquid biofuels can use existing oil distribution networks and be used in vehicles with only minor or no alterations. This is critically important, for example, to reduce emissions from existing vehicle fleets in developing countries.

There is room to further expand the use of bioenergy, but it can and must be supplied in a sustainable manner, avoiding the risk of negative impacts on biodiversity, freshwater systems, and food prices and availability. Sustainability of bioenergy has not only the environmental impacts, but also the potentially beneficial economic and social effects, for example in terms of job creation, income for rural communities, health benefits from reduced air pollution and sustainble waste management. Systems that integrate food and biofuels well also function as a buffer for agricultural price oscillations, which have negative impacts in particular on the poorest segments of the population. The critical issue is proper investment in land productivity through sustainable intensification, which will result in both more fuel and more food without adding to pressure on natural resources and ecosystems.

Governments need to invest more in innovation to unlock the benefits of new sustainable feedstocks, such as lignocellulosic residues. Further widening the feedstock base would also make bioenergy supply more responsive and resilient to sudden changes in demand. In addition, we need to expand the use of existing technologies like biomethane production to replace fossil gas while we commercialise new technologies such as biomass gasification or integrated biorefineries to co-produce biochemicals, biofuels and heat.

Recommendations

The following are the recommendations for the G20 countries to consider in their decision-making and policy implementation:

- **Boost investment** in the import and export infrastructure needed to scale up the deployment of hydrogen, synthetic hydrocarbon fuels and ammonia for clean energy technologies such as ammonia co-firing and single-fuel firing, and promote the development of resilient global hydrogen and ammonia supply chains by consolidating and increasing **international co-operation and partnerships**.
- **Expand the use of bioenergy in a sustainable manner,** considering not only the environmental aspects, but the economic and social as well.
- **Increase investment** in innovation to unlock the utilisation of new sustainable feedstocks and **expand the use of existing technologie**s like biomethane to replace fossil gas while we commercialise new technologies such as biomass gasification or integrated biorefineries to co-produce biochemicals, biofuels and heat.

5. Future-proofing existing fossil fuel infrastructure

Meeting energy security and decarbonisation needs

In the current context of high price volatility in global energy markets, governments are reducing their exposure to and dependency on fossil fuels by diversifying supply routes and sources, and by enabling the use of low-carbon fuels in existing energy infrastructure. Sourcing low-carbon fuels from several locations and from various technologies increases security of supply and protects against shocks in demand and supply.

Creating new infrastructure requires high levels of investment and brings the risk of delay from the need to obtain different permits and approvals. The repurposing of existing infrastructure offers the prospect of accelerating the transition. For instance, existing thermal assets can provide the flexibility that variable renewable energy sources call for, complementing other sources, such as transmission, storage and demand response, while securing emission reduction benefits if they are run on lower-carbon fuels.

The decommissioning of existing infrastructure can cause economic disruption for local communities that are dependent on it for employment and revenues. Leveraging existing strengths to identity new uses for existing infrastructure during the transition can bring many benefits. Notably, repurposing or converting existing infrastructure allows for the preservation of large parts of the value of the infrastructure, while retaining jobs and tax bases in communities where the infrastructure is located. For instance, a number of current oil and gas producing countries are currently developing or looking to develop CCUS, hydrogen and offshore wind energy industries, using existing skillsets and knowledge bases from oil/gas production, including offshore.

Policy makers should assess the opportunities for scaling up the deployment of low-carbon fuels using today’s energy infrastructure before giving the owner consent to reclaim or demolish existing infrastructure along the entire value chain. Such a forward-looking and people-centred approach to existing energy infrastructure could lead to substantial cost savings and improve the resilience of the energy system.

Transitioning oil infrastructure

As with other fossil fuels, the oil industry will be affected by both decreasing demand for its products and the need to decarbonise its activities. As overall investment falls back and markets become increasingly competitive, only those with low-cost resources and tight control of costs and environmental performance would be in a position to survive.

Onshore oil production infrastructure, encompassing wells, gathering pipelines and processing infrastructure, has little room for conversion to other uses. Offshore oil production facilities, in particular the platforms, have the potential to be repurposed as bases for offshore wind or aquaculture. Crude oil and product pipelines could potentially be converted to CO_2 or hydrogen transit infrastructure. There is also some room for seaborne transport infrastructure, such as ports, jetties, storage facilities and vessels, to transition towards dealing with hydrogen, biofuels and ammonia. For instance, tanks for liquefied petroleum gas (LPG) are easy to divert to ammonia storage. The rise of electrically powered boats and vessels will also require charging infrastructure at ports.

Refineries have already started the transition, with some 483 kb/d of global refining capacity already converted to biorefineries and plans for 702 kb/d more in the medium term. Repurposing existing refinery capacity for upgrading biofuel intermediates, such as bio-oils and Fischer-Tropsch wax, could reduce the investment needs associated with increasing biofuel deployment. Higher shares of biofuels in the transport fuel pool will also require more complex blending and storage operations.

Besides complete site conversion, refineries are also increasingly engaged in co-processing renewable feedstock together with petroleum. The refiners' entry into biofuels production also involves midstream, marketing and blending activities, with the conversion or construction of the required infrastructure. However, not all refineries can be converted to biofuels production given the practical impossibility of procuring sufficient feedstocks for all of them.

Another pathway for refiners is the circular economy. As a complex industrial sector with suitable equipment, highly skilled workers, researchers and engineers, refiners can develop and demonstrate technologies for the chemical recycling of plastic waste and waste oil along plastics-to-plastics or plastics-to-fuel paths.

To enable the production of low-carbon fuels, existing refineries need to make significant investment. In the production of e-fuels, the technology combines electrolytically generated hydrogen with carbon monoxide (from sequestered carbon) to create syngas. Syngas is then converted to synthetic oil via Fischer-Tropsch processes, and becomes feedstock for renewable transport fuels or petrochemical feedstocks. This pathway could be interesting in regions where options for geological carbon storage are limited or non-existent.

Refining is the world's largest hydrogen-consuming sector. It sources its hydrogen needs almost entirely from oil (naphtha reforming) or natural gas (steam reforming). By 2026, more than 500 MW of electrolysis projects, associated with refineries, are expected to have come online in Europe, producing some 37 000 t per year of green hydrogen, representing only 0.1% of total hydrogen demand from the refining sector. Another 1 200 MW worth of projects have not reached the final investment decision (FID) stage yet, but may come online in the same timeframe if favourable policies are adopted.

The retail segment, or oil marketing and distribution, is also set to undergo significant change during energy transitions. Many of them already offer charging facilities for electric vehicles. In the future, depending on transport electrification paths, they could also host battery swapping operations and offer hydrogen refuelling.

Repurposing natural gas infrastructure

Low-carbon gases (including biomethane, low-emission hydrogen, synthetic methane and methane subject to CCUS) are set to play a key role in decarbonisation pathways.

In the IEA Net Zero Scenario, low-carbon gases account for close to 75% of total gaseous fuels in total final energy consumption in 2050, and for the majority of gaseous fuels consumed in the power sector.

In turn, low-carbon gases keep the share of gaseous fuels in total final energy consumption close to today's levels and play a key role in the hard-to-abate sectors, including industry, long-haul transport and seasonal energy storage. In the power sector, low-carbon gases are set to provide flexible back-up supply in a system dominated by variable renewable sources of electricity supply.

The existing gas infrastructure can fast-track the deployment of low-carbon gases, by providing network access, reducing transport costs and ultimately facilitating their integration into the broader energy system.

At the upstream level, natural gas and condensate fields, depleted gas reservoirs and their related above-ground infrastructure could be used for CO_2 storage, enabling the deployment of CCUS-based solutions as in the production of hydrogen from methane.

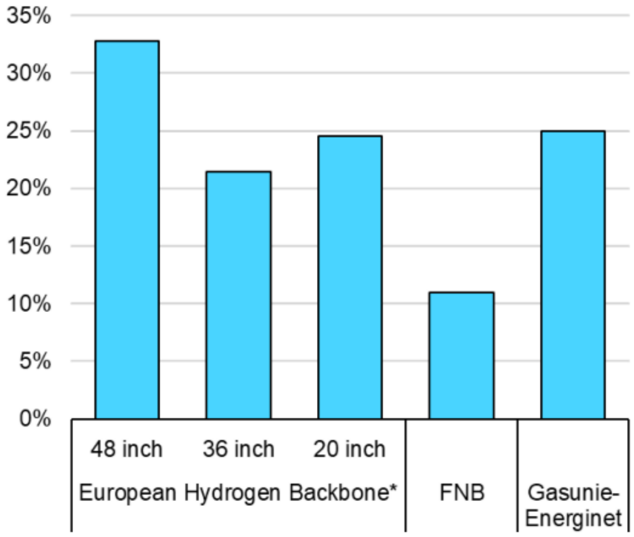
The vast system of gas transmission and distribution pipelines can be repurposed to carry low-carbon gases. Biomethane and synthetic methane are perfectly interchangeable with conventional methane due to their almost identical chemical and physical properties. Nevertheless, they will require the development of standards to ensure uniform gas quality across interconnected gas systems and diminish any risk of deviating from them.

Biomethane is mainly fed into distribution networks due to the decentralised nature of its production. In the longer term, the high penetration of biomethane at the distribution level will necessitate closer integration between transmission and distribution networks. Bidirectional compressor stations would enable reverse flows from distribution to the transmission network, facilitate daily balancing and provide access to biomethane for seasonal gas storage sites (which are most often connected to the transmission system).

In the case of low-emission hydrogen, blending can provide a temporary solution until dedicated hydrogen transport systems are developed. Depending on the characteristics of the gas transmission system, hydrogen can be blended at rates of 2–10% H_2 by volume without substantial retrofitting of the pipeline system. The hydrogen tolerance of polymer-based distribution networks is typically greater, potentially allowing blending of up to 20% with minimal or possibly no modifications to the grid infrastructure.

Natural gas pipelines can also be repurposed to serve as hydrogen distribution. Pipeline repurposing can be substantially less costly and the lead times much shorter compared to new-build hydrogen networks.

Cost of repurposing natural gas pipelines as a percentage of building new hydrogen pipelines



* Including compressor station CAPEX costs.

Note: FNB = Vereinigung der Fernleitungsnetzbetreiber (Transmission System Operators Association of Germany).

Sources: Based on FNB (2020), Netzentwicklungsplan 2020; Gas For Climate (2021), European Hydrogen Backbone 2021; Gasunie-Energinet (2021), Pre-feasibility Study for a Danish-German Hydrogen Network.

Certain studies suggest that pipeline conversion costs are 21–33% of the cost of a new hydrogen pipeline (figure above). Ultimately, these cost savings could translate into lower transport tariffs and improve the cost-competitiveness of hydrogen.

The seasonal and short-term supply flexibility of low-carbon gases can be enhanced via the utilisation of existing underground gas storage sites. Global storage capacity is close to 430 bcm (or about 10% of global gas demand), with porous formations (depleted fields and aquifers) accounting for over 90% of storage capacity and salt caverns for the remaining 10%.

Biomethane and synthetic methane are well-suited to being stored in underground facilities as they have identical physical and chemical characteristics to natural gas. Storing hydrogen underground in salt caverns is a proven technology and existing salt caverns could be potentially converted to store hydrogen (although this remains to be demonstrated). There is no practical experience in storing pure hydrogen in porous reservoirs and further research is required.

Repurposing coal infrastructure

Repurposing coal infrastructure can accelerate just and secure energy transitions. The most interesting asset in the coal value chain is generally the coal power plant and its associate infrastructure, in particular the connection with the electricity transmission grid. There is currently over 2 000 GW of coal power generation capacity that could be converted into low-carbon assets in different ways, providing adequacy, flexibility and stability to the electricity grid.

The first option is to retrofit the plants with CCUS. Another option is to use low-carbon fuels, such as sustainable biomass, or ammonia produced from renewable hydrogen or fossil fuels in combination with CCUS. Conversion to biomass has already been done in some plants around the world, and the project of ammonia co-firing is making good progress such as Gresik Thermal power plant in Indonesia. In addition, technological development of co-firing high shares of ammonia and ammonia single-fuel firing is progressing as well. Biomass has an additional advantage in that, when combined with CCUS, it can turn coal power plants, currently the largest source of CO_2 emissions, into a source of negative emissions. Other possibilities like conversion to a nuclear facility, thermal storage or a combination of the two should not be overlooked. The conversion or retrofitting of existing coal power plants offers many advantages, in particular the prospect of faster permitting processes and use of an existing electricity grid connection, two important bottlenecks identified in clean energy transitions.

Recommendations

The following are the recommendations for the G20 countries to consider in their decision-making and policy implementation:

- **Evaluate** the potential **to repurpose redundant oil, gas and coal infrastructure** to produce or transport or use low-carbon fuels (such as hydrogen and hydrogen-derived fuels) before such infrastructure is decommissioned.
- Assess the possibility of using depleted reservoirs and associated above-ground infrastructure for CO_2 storage, as well as repurposing offshore production platforms into offshore wind generation sites.
- **Consider the conversion of redundant oil and gas storage facilities** into storage for low-carbon fuels, as well as utilising gas pipeline infrastructure for transporting low-carbon gases and hydrogen.
- **Assess** the possibility of **converting excess refining capacity into biofuels production facilities** and **ensure that adequate support** is given to retailers to facilitate the sale of low-carbon transport fuels and integration of charging infrastructure.
- To avoid creating stranded assets, ensure that full consideration is given to **future-proofing any new oil and gas infrastructure projects** before investments are finalised by taking into account the potential to use the infrastructure for low-carbon fuels at some point in the future.
- **Assess how the operation of existing oil and gas infrastructure can be decarbonised,** including using renewable energy to power offshore platforms and refineries, and seeking to integrate green hydrogen production facilities with refining operations.

6. Establishing a secure and diverse supply of critical minerals

Achieving widespread transitions to clean energy depends on the pace of deployment of new clean technologies across the world. And as demonstrated by the reduced energy supplies to some countries in the aftermath of Russia's invasion of Ukraine, maximising domestic renewable energy production can add greatly to energy security and energy independence. However, these depend entirely on the continuous availability of critical minerals. Therefore, it is essential to ensure security and diversity of supply of critical minerals while recognising the range of pathways to approach carbon neautrality by or around mid-century.

The clean energy transition relies on critical minerals

Building solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally requires much more minerals than their fossil fuel-based counterparts. A typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired power plant per megawatt. Lithium, nickel, cobalt, manganese and graphite are crucial to battery performance, longevity and energy density. Rare earth elements are essential for permanent magnets that are vital for wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper also being a cornerstone for all electricity-related technologies.

According to the IEA report The Role of Critical Minerals in Clean Energy Transitions, there is a looming mismatch between the world's strengthened climate ambitions and the availability of critical minerals that are essential to realising those ambitions. Global clean energy transitions will have far-reaching consequences for mineral demand over the next 20 years. By 2040 total mineral demand from clean energy technologies quadruples if the world follows a pathway limiting global temperature rise to below 2°C.

EVs and battery storage account for about half of the mineral demand growth from clean energy technologies over the next two decades, spurred by surging demand for battery materials, which grows over 30 times in the period to 2040. By weight, mineral demand in 2040 is dominated by graphite, copper and nickel. Lithium sees the fastest growth rate, with demand growing by over 40 times to achieve the climate target. The shift towards lower cobalt chemistries for batteries helps to limit growth in cobalt demand, but it is displaced by growth in nickel. Wind power plays a leading role in driving demand growth due to a combination of large-scale capacity additions and higher mineral intensity (especially with growing contributions from mineral-intensive offshore wind). Solar PV follows closely, with its unmatched scale of capacity additions among the low-carbon power generation technologies. Hydropower, biomass and nuclear make only minor contributions given their comparatively low mineral requirements and modest capacity additions.

Price may also heavily influence the uptake of critical minerals. The price of many minerals and metals that are essential for clean energy technologies have recently soared due to a combination of rising demand, disrupted supply chains and concerns around tightening supply. The prices of lithium and cobalt more than doubled in 2021, and those for copper, nickel and aluminium all rose by around 25% to 40%. The price trends have continued into 2022. The price of lithium has increased by an astonishing two and a half times since the start of the year. The price of nickel and aluminium – for which Russia is a key supplier – has also kept rising, driven in part by Russia's invasion of Ukraine. For most minerals and metals that are vital to the clean energy transition, the price increases since 2021 exceed by a wide margin the largest annual increases seen in the 2010s. While innovation and economies of scale rapidly reduced the cost of key clean energy technologies such as solar PV and batteries, surging raw material prices could now reverse these gains, with a major impact on the financing needs for clean energy transitions around the world. Raw materials now account for a significant and growing share of the total cost of clean energy technologies.

Production of critical minerals is not adequate

Limited availability of critical minerals at this stage, and also in the coming decades, would not only slow the transformation to clean energy and make a transition to net zero impossible, but would also place additional demands on current energy systems, strained to the limit already. This may have very significant security of supply consequences. In addition, if obsolete and inefficient generation capacity, car fleets and grids cannot be substituted with new clean technologies in a timely manner, the climate challenge would no longer be solvable, putting at risk global economies and human wellbeing.

An energy system powered by clean energy technologies differs profoundly from the one fuelled by traditional hydrocarbon resources. Production of many critical minerals indispensable for the transformation of energy systems is more concentrated than that of oil or natural gas. For lithium, cobalt and rare earth elements, the world's top three producing countries control well over three-quarters of global output. In some cases, a single country is responsible for around half of worldwide production. Southeast Asia is a key player in supplying a range of critical minerals. For example, according to the IEA Southeast Asia Energy Outlook 2022, Indonesia and the Philippines are the two largest nickel producers in the world; Indonesia and Myanmar are the second and the third largest tin producers; Myanmar accounts for 13% of global rare earth element production; and Southeast Asia provides 6% of global bauxite production.

There is yet another very significant risk factor for the development of clean technologies based on critical minerals, namely societal support. There is no doubt that the rapid expansion of activity necessary to extract the minerals, and then process and refine them, ready for use in high-technology products, needs wide backing from society, especially within producing countries. We have already seen a number of instances where social opposition to mining projects and severe labour conditions have created operational challenges. It is therefore crucial to win such support from the very beginning of developing new projects, especially by creating added value in local communities as an element of people-centred energy transitions.

Ensuring security of critical minerals and preparedness

The security of critical minerals also requires a new systemic approach to emergency preparedness in the face of supply disruptions, including greater transparency of markets that today are often opaque and at times speculative. Establishing new trade patterns, including through intergovernmental arrangements, diversified and more dispersed production and the creation of strategic stocks, may all ensure undisrupted supplies. Setting high standards of resilience against climate, technological and cyber threats may in turn add greatly to stabilising supply chains.

Strategic management of resources must also include enhanced recycling and reuse, stronger supply chain resilience and sustainability, and greater RD&D into substitutes for clean energy systems. The objective should be to support investment in new sources of supply and the development of a circular economy that accelerates clean energy transitions and ensures affordable security of supply.

Environmental, social and governance (ESG) standards are all the more important as meeting the exponential growth in demand for critical minerals will require a significant increase in mining and mineral processing, whereas today some supply chain elements lack any standards. If not managed appropriately, the deficiency of ESG regulations could not only lead to the disruption of critical mineral supply, but also significantly erode the health and safety of workers and undermine local communities.

The shift to a clean energy system is set to drive a dramatic increase in the need for critical minerals, meaning that the energy sector is emerging as a major force in mineral markets. The mineral-intensive economy is becoming an irreversible fact and it is the task for governments and stakeholders to create a market for critical minerals that is transparent and competitive, and has high environmental standards.

As stated above, the supply side of critical minerals faces huge challenges in delivering sufficient volumes, and without clear signals for "going green" from governments, investors are less likely to risk investing in new mining and processing projects to increase supply.

Governments hold the keys to all policy aspects of security of supply of critical minerals. They range from providing clear signals of action on decarbonisation to remove uncertainty of demand as the greatest risk factor; through measures to strengthen adequacy of supply; to using public funding and support for research capacity to advance technological responses that have a potential to fill the gaps creating existing imbalances. Even though many governments and regions have already attempted to draw up critical mineral strategies, they need co-ordinated policy action for their effective implementation given the sectoral interdependencies and the global scale of minerals markets. And early engagement of market operators in designing policies and market support measures is essential before taking any action. Providing conditions conducive to market stakeholders making sufficient investment is the ultimate goal of policy action.

Governments play a strong role in ensuring critical minerals security

Among the more targeted measures that governments may employ to help accelerate increased supplies are:

- Lessening and shortening the administrative burden related to extending existing and opening new production projects, including permitting procedures and tax obligations.
- Public funding of pre-commercial mapping data and geological surveys.
- Grants to early- to mid-stage projects to allow them to survive through the pre-profit stage.
- Loans through dedicated investment facilities and investment attraction through measures such as binding mineral offtake arrangements.
- Security of critical mineral supply is a challenge that can only be met jointly, guided by producer and consumer governments. Until now this market has to some extent been governed by arbitrary rules, with producers using all available methods of

production at scale and consumers searching for products without having much choice.

- No country in the world can assure its own secure supplies alone and close the supply chain within its boundaries. The need to co-ordinate policy security efforts is therefore pressing. Any delay in this regard could hamper proper market organisation, at a time when the world can least afford it in view of expected demand growth.
- Formalised co-operation should be particularly be aimed at knowledge sharing and capacity transfer to ensure sustainable and responsible development of critical mineral markets. Facilitating enhanced collaboration between producers and consumers, both at the country and company level, would result in a better match of expectations and large-scale problem-solving. Direct and open collaboration may be particularly sought by incumbent producers striving to make their capacity more resilient and better prepared for market expansion.

At the IEA Ministerial Meeting in March 2022, IEA member countries voted to endorse and deepen the IEA's work on critical minerals as part of the agency's new mandate to strengthen and broaden its work on energy security. Since that time, the IEA has created the Critical Minerals Working Party, a forum that can play a vital role in bringing together all stakeholders, including governments and business communities, to deliver tangible solutions to the critical minerals market.

Recommendations

The following are the recommendations for the G20 countries to consider in their decision-making and policy implementation:

- **Send clear, unconditioned signals to markets that clean energy transitions are irreversible** policy principles, to ensure that clean technologies based on critical minerals develop according to the best standards and are deployed more quickly.
- **Create an environment that is conducive to large-scale investment in new projects** to increase the supply of critical minerals along value chains, including by reducing and shortening permitting procedures, offering public assistance and financing, and committing to binding offtake wherever appropriate to support new capacity.
- **Apply a new systemic approach, including the stockholding of critical minerals, to ensure security of supply**. ESG standards are all the more important as meeting the exponential growth in demand for critical minerals will require a significant increase in mining and mineral processing.
- Ensure that G20 countries participate in the international efforts aimed at developing a well organised, standardised and stable market for critical minerals globally, including through the **IEA Critical Minerals Working Party**.

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